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OPTIMAL NUCLEAR RADIATION CRITERIA FOR AERONAUTICAL SYSTEMS

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OPTIMAL

NUCLEAR RADIATION CRITERIA

FOR AERONAUTICAL SYSTEMS

Rayford P. Patrick

INTRODUCTION

Military systems with strategic or tactical nuclear warfare roles may be exposed to the environments generated by nuclear detonations. The capability of the system to retain its mission completion capability after such exposures is termed nuclear hardness and is a critical part of the system's nuclear survivability.

Extensive and detailed analyses have been conducted in the past to determine the nuclear hardness criteria necessary for acceptable survivability. However, because many of the inputs to these analyses are estimates at best, they could change at any time, and almost certainly would change during the operational life of the system, possibly resulting in less than adequate hardness. In fact, since similar analyses are conducted for each new system, nuclear hardness criteria across the Air Force (and DOD) are a potpouri of requirements.

Differing blast and thermal criteria are of little concern. They apply almost exclusively to structure, and/or to exterior system elements, (e.g. radomes, fuselages, control surfaces, etc.) which are unique to the system of interest. The nuclear radiation criteria (and the EMP interface requirements, which are subsystem level requirements, and not addressed in this paper) however apply to radars, radios, voltage controllers, instruments, computers, multiplex components, and all other modern subsystems utilizing semiconductor technology. Once a new electronic subsystem/component has been developed, it could be used in many other applications. However, differing nuclear radiation requirements severely hamper common useage, interchangeability, use in future systems, and the development of an integrated hardness maintenance program. Along with this limitation is an overall increase in the logistic support costs ... it costs more to support many small-count unique subsystems than one common large-count subsystem.

The introduction of digital equipment into military systems has increased the urgency of the development of commonality, not just in nuclear hardness, but also in data multiplexing procedures, in common computer language, and other factors so that various equipment can communicate directly without costly and complex interface units serving as interpretors. MIL- STD-1750, MIL-STD 1553, and MIL-STD-1589 are some of the milestones to date in that effort.

A key player in future systems will probably be the DAIS (Digital Avionic Information System), an advanced development program managed by the Air Force Avionics Laboratory. This program was initiated in 1974 to "demonstrate a coherent solution to the problem of proliferation and nonstandardization of aircraft avionics, and to permit the Air Force to assume the initiative in the specification of avionics configurations for future Air Force weapon systems acquisition at greatly reduced costs".* The DAIS concept is the use of building blocks (i.e. small units of central processor, and memory), with the required software, controls and displays, and multiplexing. A system with small processing needs may use one each control processor, and memory unit, while a large, manned bomber may use several to get the computing capacity required. Those building blocks, software and peripherals would constitute the system "nerve center" which communicates with the various sensors (radar, radio, TACAN, etc.) via multiplexed data busses. Note that the building blocks, software, and multiplexing technique would be common Air Force wide.

However, for the DAIS concept to be successful, common hardness requirements must be developed and utilized Air Force wide.

There then are potentially enormous benefits to be gained if a basic set of nuclear radiation hardening criteria could be developed and applied throughout the Air Force. Such criteria must satisfy basic survivability requirements, and be technically achieveable at reasonable cost.

This paper contains brief discussions of electromagnetic pulse (EMP), blast, and thermal criteria, but concentrates upon nuclear radiation. A set of common nuclear radiation criteria are developed and detailed supporting rationale are presented.

DISCUSSION

For aeronautical systems, the nuclear environments of interest are depicted in figure 1, along with estimated ranges of practical hardness levels for each environment. The first estimate corresponds to the inherent hardness level of systems designed with no hardness consideration, and the second roughly corresponds to the maximum realistically achieveable hardness level for aeronautical systems.

The analyst's task is to select those levels of hardness which optimize the system's mission completion capability. He must consider the system's present and future mission, present and future enemy capabilities, cost to harden (and maintain hardness), tactics, and numerous other factors during the course of the analysis. His best approach to selecting highly credible and defendable criteria is to limit the analysis as much as possible, i.e. to establish believable worst-case situations which the system could experience. Pertinent parameters within the constraints of those few situations then would be varied to fix optimum system hardness criteria.

* AFAL letter, "Status Summary of the Digital Avionics Information System", 8 May 1979 from Mr. T. A. Brim, Acting Chief, DAIS Program Branch.

FIGURE 1

NUCLEAR ENVIRONMENTS

APPLICABLE FOR AIRCRAFT

BLAST		
OVERPRESSURE	-	0.5-3 PSI (1 MT)
GUST	-	50-150 FT/SEC (1 MT)
THERMAL	-	15-80 CAL/CM^2 (1 MT)
NEUTRON FLUENCE	-	10^9-10^{13} N/CM^2
GAMMA RATE	-	10^6 - 10^9 RAD (SI)/SEC
GAMMA TOTAL DOSE	-	500-10,000 RADS (SI)
EMP	-	HIGH ALTITUDE DETONATIONS

Electromagnetic Pulse (EMP)

The nuclear criterion most easily defined for aeronautical systems is Electromagnetic Pulse (EMP). All nuclear detonations produce EMP, but those within the atmosphere produce localized EMP environments which are of much less significance to nearby aeronautical systems than the EMP from high altitude detonations. The reason is that the local EMP at ranges from the atmospheric detonation compatible with the system surviving exposure to other nuclear environments is usually benign in comparison to the high altitude EMP.

A high altitude detonation outside the sensible atmosphere (above 25 km) generates high energy gamma photons which interact with the upper atmosphere freeing vast numbers of electrons. Those freed elections tend to follow the earth's magnetic field lines cyclotronically, radiating broadband electromagnetic energy. This phenomenon occurs essentially line-of-sight from the detonation.

The EMP exposure volume encompasses the majority of the atmosphere for a thousand or more miles in all directions from the detonation. For example, a detonation over Omaha, Nebraska would subject the entire continental United States to significant levels of EMP. Therefore system (and fleet) survivability depends upon the capability of the systems to withstand exposure to the high altitude EMP.

Blast and Thermal. The next nuclear environments in terms of ease in defining criteria are blast and thermal. These two environments will be discussed togather because normally they are derived concurrently and are balanced.

The blast environment relates to the shock wave generated by the detonation. The nuclear blast environment historically has been broken into two parts, overpressure and gust velocity. The overpressure environment is simply the static pressure increase across the shock wave, while the gust velocity is the air motion a stationary observer would experience immediately after shock wave passage. The overpressure environment has usually been specified in psi, and the gust velocity in feet/second. Since shock wave parameters vary with altitude, both environments usually have been called out as point design requirements at sea level. However, use of a constant dynamic pressure, q, behind the shock would probably be a better criterion since it minimizes the altitude dependence of system response.* Associated with the constant dynamic pressure would be corresponding gust and overpressure environments, which vary significantly with altitude.

The thermal environment is generated by the fireball. This environment strongly depends on detonation altitude and weapon yield. The thermal environment is generally specified in terms of a total fluence (calories/cm^2) for a specific weapon at a specific altitude. Often, the corresponding flux (calories/cm^2/sec) is also provided.

* Patrick, R. "Nuclear Hardness and Base Escape", Eng-Study S-112, SAC/LGME, Offutt Air Force Base, Nebraska, March 1981.

The blast environment is probably the most severe aeronautical system threat for large yield weapons at low altitude because of enhancement of the destrucive power of the blast wave caused by reflection (and build up) of the shock from the earth's surface. This happens also to be the most probable enemy attack mode for aircraft on ground alert. Therefore base escape is generally the most logical basis for defining optimum blast (and associated thermal) criteria.

Base escape analyses are complex and lengthy. Detailed gust, overpressure and thermal response models of the system are required as well as accurate performance data. These inputs are then played off against the blast and thermal environments generated by numerous yields, heights of burst, and postulated enemy attack strategy (a single detonation over the runway, pattern attacks, etc.). Based on results of these efforts, blast and thermal criteria can be obtained.

Nuclear Radiation Environments: It was noted above that the EMP, blast, and thermal environmental criteria were relatively straightforward to define and defend. In each case, the threat was evident, survivability needs apparent, and necessary analytical techniques available to determine criteria needed for acceptable survival. Consider now the nuclear radiation environments consisting of neutron fluence (n/cm^2), gamma dose rate (rads(Si)/sec) and gamma dose (rads(Si)). As before, let us attempt to limit the scope of the criteria selection analysis.

Consider first base escape. It is evident that the system must survive attack on its base in order to be able to complete its mission. Therefore, nuclear radiation environments comparable to the blast and thermal criteria resulting from the base escape analyses shall be investigated. The system must not survive the blast and thermal environments and then be crippled by corresponding nuclear radiation environments.

This evaluation yields the results that typical neutron fluences and gamma dose rate environments corresponding to mission completion levels of blast and thermal for base escape are very low. Neutron fluences and gamma dose rates of about $10^8 n/cm^2$ and 10^6 rads (Si)/sec respectively would provide the needed balance. The reason for such low values is that large yield weapons were used to maximize kill ranges. The major kill mechanism of such weapons are blast and thermal. Corresponding prompt radiation environments are relatively insignificant and are equal or lower than the inherent hardness level of unhardened systems.

Once the system has successfully escaped from its base, the major threat to it is the penetration of radioactive dust clouds. Such clouds could originate from enemy attacks on our hardened missile sites and other hardened targets upon which he would likely use surface detonations with primary kill mechanisms of ground shock and cratering. Surface detonations result in tremendous quantities of soil being vaporized and injected into the

atmosphere. In addition, the associated winds would pick up more dust and carry it up into the fireball and stem. The radioactive clouds so formed will be convected by normal surface winds and in a few hours could have spread far from the original ground zeros. Penetration of such clouds (which may not be detectable via conventional means) could result in the accumulation of total dose by both the aircrew and electronic equipment. Exact quantities would vary with exposure, nearness to any accumulated dust in the system and filter, etc.* During this mission phase, the probability of the system being subjected to prompt radiation environments (neutron fluence and gamma dose rate) is relatively small. The systems are not near enemy territory; therefore, enemy capability to search them out and attack them is questionable. (However, if he developed the capability, would he attack them via submarine launched ballistic missile (SLBM), inter continental ballistic missile (ICBM), penetrating aircraft, or other means; and would he use large-yield or low-yield weapons?)

Systems with a requirement to penetrate and attack targets in hostile territory will have a higher probability of being attacked --- but will the attack be with non-nuclear missiles (to lessen the enemy's collateral damage) or with nuclear tipped missiles, and if nuclear tipped, what yield? Enemy sizing of nuclear weapons may depend upon penetration altitude, population density of penetration corridors, warhead cost, and other factors. High-yield weapons provide larger kill radii, but also at a larger collateral damage cost. On the other hand, very low-yield, radiation enhanced weapons ("neutron bombs") would result in little collateral damage, yet provide much larger kill radii than conventional warheads.

Note that the above discussion does not yield any specific threat, encounter altitude, or other factors upon which to base survivability analyses. The best the analyst can do is make parameteric solutions and attempt to select "best fit" nuclear radiation criteria for the most probable threat/scenario-/cost/strategy combination. The great danger in this sort of "soft" analysis is either selection of unrealistically high levels of nuclear radiation hardening criteria, or selection of very low radiation criteria. The first could result in excessive cost, both during the design/verification and during subsequent hardness assurance/hardness maintenance programs. The high levels could also constrain designers to exotic and expensive designs based on unproven technology.

On the other hand, very low levels could result in vulnerabilities which, during the possibly decades-long life of the system, could seriously threaten its survivability (and its strategic deterrent credibility). Such low nuclear radiation criteria may also allow use of design practices/techniques or the implementation of marginal components which may prove totally impractical to ever correct. For example, low, or non-existent nuclear radiation criteria could allow uncontrolled use of CMOS and/or NMOS semiconductors in mission critical subsystems. These devices have susceptibility

* R. Patrick, et al, "Aircraft Penetration of Clouds Generated by Nuclear Bursts", AFWL-TR-73-82, Air Force Weapons Laboratory, Kirtland AFB, NM, September, 1974.

thresholds of about 800 rads (Si) and 10^6 rads (Si)/sec.* If such thresholds prove later to be inadequate because of a change in threat (or a change in how we percieve the threat) massive redesign would be necessary. The cost of hardening could rival or exceed the total original cost of the system. Another critical danger in the use of low criteria, especially for a major system, is the proliferation of the subsystems (and their vulnerability) to other existing or development systems. Therefore, the use of any criteria could set a precedent. We must be ever careful to set a sound one.

One last limitation to the selection of low criteria is the degradation in flexibility, i.e. growth potential to accomodate possible future defensive systems such as advanced electrocounter measures (ECM), bomber defense missiles, directed energy weapons and other advanced defenses which may require definite keep out ranges.** Lack of nuclear radiation criteria could result in keep out ranges being not only large, but also highly variable among the various subsystems of a system, and even among systems. Therefore taking advantage of a future defensive system breakthrough could prove extremely difficult and/or costly.

It was found above that a firm basis for the establishment of nuclear radiation criteria can not be found in the threat/senario type of considerations. Consider now the aircrews. Maybe human vulnerability to nuclear radiation could be a balance point for system nuclear radiation criteria.

The human is indeed susceptible to nuclear radiation, but the susceptibility varies greatly with individual, the severity and complexity of the task loading, tolerance of the system to momentary lapses in capability of the human to respond, the length of time after exposure that performance is required, the type of radiation, shielding provided by the structure (inadvertent or deliberate)***, and numerous other factors. Therefore the definition of a mission completion crew dose must be done statistically. (We do not have the option of specifing a mission completion hardness criteria for aircrews.) However this "mission completion" is considerably

* Meyer, D., "Semiconductors in a Nuclear Environmet", PROGRESS, Fairchild J. of Semiconductors, Fairchild Instrument Corp., Mountain View, CA, July/August/September 1980.

** For example, increase of gamma dose rate hardness (and associated neutron hardness) from 10^7 rads (Si)/sec to 10^8 would decrease the keep out range from 3600 feet to 2600 feet. A high energy laser beam is attenuated by the atmosphere largely by absorption, i.e. Intensity $\sim e^R$. Therefore the above decrease in needed keep out range would reduce the required beam- power-on-target by a factor of 3, (or more, if scattering, beam dispersal and other considerations are included).

*** Quite effective shielding to high-energy neutrons can be provided with relatively small volume and weight impacts.

different from that used on hardware. For hardware the hardness criteria are based on mission completion ... but to account for possible statistical variations in response and other potentially debilitating factors, overdesign is usually incorporated to almost guarantee that the achieved hardness equals or exceeds the criteria. On the other hand the human mission completion dose may be defined as the dose resulting in adverse affects in a given percentage of the human population performing a certain task. The mission completion dose then depends upon the task, the percentage of crews affected, the kind of effect (nausea, emesis, collapse, etc.), the expert opinion of the estimator, and numerous other factors. In short, aircrew mission completion doses vary enormously and provide no firm basis for hardware criteria. However, there is one dose which appears to be acceptable to the entire community, a mission kill total dose of 5000 rads (tissue)*. Such a dose corresponds to permanent loss of mission completion capability of 90% of aircrews within minutes.

This dose can be used as a base for the nuclear radiation criteria on the grounds that the hardness must be sufficient to ensure functioning equipment up to the point where the most hardy aircrews succumb.

However, the dose above is in terms of rads (tissue). Recall that the definition of rad is the quantity of ionizing radiation resulting in the absorption of 100 ergs of energy by a gram of material. Therefore associated with the term "rad" must be the identification of the absorbing medium, i.e. tissue in the above. Usually for aeronautical systems, two basic materials are of interest, tissue and silicon. Tissue is the living body tissue of crew members and silicon is the major material used in semiconductors. Since the crew and the semiconductor components of electronic equipment are most susceptible to ionizing radiation, the doses absorbed by them (and the effects caused by the absorbed doses) are of major interest.

It is stressed that the same amount of radiation does not produce the same absorbed dose (rads) in different materials. For tissue and silicon, there can be significant differences. For example, energetic neutrons (1-10 MeV) result in about thirty times more dose accumulation in tissue than in silicon (because of the hydrogenous nature of tissue). Therefore one rad (silicon) corresponds to 30^+ rads (tissue) for 1 MeV neutrons. For the other ionizing radiation of major significance, i.e. gamma photons of about 1 MeV, the difference is much less significant, the tissue dose is only about ten percent larger.

Therefore, we cannot simply apply a 5000 rads (tissue) dose to hardware, because this crew dose can be obtained in an infinite number of ways via combinations of exposures to prompt neutrons, prompt and delayed gammas, radioactive cloud penetrations, low-level fly overs of contaminated surface regions, etc. At this point then we must consider other means to fix hardware criteria corresponding to the crew mission-kill dose.

* T. Mobley, C. Olson, and T. Lauritsen, "The Effect of Thermal and Ionizing Radiation on Aircrews". AFWL-TR-76-141, Air Force Weapons Laboratory, Kirtland AFB, NM, August 1976.

Consider first the hardness thresholds of various semiconductors. Table I is an extract of data from an article* summarizing the results of numerous tests on modern semiconductors. The effects of neutron fluence, gamma dose rates, and gamma total dose are addressed relative to modern semiconductors, including CMOS and NMOS which are in widespread use.

Prior to continuing, a brief discussion of the type of responses/effects caused by each of the environments should aid the reader. The neutrons cause displacement damage to the crystal lattice structure, causing degradation in the gain. Large bipolar devices used in power supplies are particularly susceptible to this kind of damage. Gamma dose rate consists of a large number of high energy photons in a short pulse. These photons interact with the semiconductor material, freeing elections which constitute transient photocurrents. The photocurrents can turn on zenors, silicon controlled rectifiers, and bipolar devices. They could also cause upset in computer memories, could result in latchup in integrated circuits (CMOS devices are particularly susceptible), and even burn-out of devices inadvertently turned on --- if there is little series resistance in the circuit. Gamma total dose is simply the sum total of all the gamma photons impinging on the semiconductor during a given mission. The major effect of the gamma dose is a surface charge buildup in the dielectric material which can cause shifts in device characteristics, e.g. threshold voltages of MOS devices. NMOS devices are very susceptible, having a threshold of about 800 rads (Si).

The table contains susceptibility thresholds for the various environments. The minimum hardness criteria should be slightly above the threshold to insure the elimination of "sports" and "mavericks" from the population.** With that in mind, gamma dose rate and gamma total dose levels of about 10^8 rads (Si)/sec and 1000 rads (Si) should be achievable with relatively small extra effort. The neutron fluence corresponding to the gamma dose rate for the small yield detonations expected for enemy air defense against low-level penetrators, would be about 3×10^{11} n/cm^2 (1 MeV SDE). (Note that neutron fluence usually is referred to a silicon damage equivalent (SED)). This neutron fluence corresponds closely to the threshold values listed in the table.

Let us now analyze a typical mission and estimate upper bounds on the environmental levels for such a mission. Such an analysis for a manned, low-level penetrator has been done*** and table 2 contains the results. This analysis considered all aspects of the mission from base escape through penetration, including low-level flyovers of contaminated surface areas while conducting damage assessments for restrike considerations. Note that 1300 rads (Si) of the 2270 rads (Si) total was attributed to dust accumulations in the plenum, or cooling chambers, of the electronic equipment. If a filter were used in the cooling air supply or if fluid cooling were used, the total dose accumulation reduces to 970 rads (Si).

* D. Meyers, "Semiconductors in a Nuclear Environment", Progress, Fairchild J. of Semiconductor, Fairchild Camera and Inst Div., 464 Ellis St., Mountain View CA, July/August/September 1980.

** "Sports" and "mavericks" are those devices unusually susceptible to the nuclear environment, i.e. they fall in the tail of the probability distribution.

*** R. Patrick, "Total Ionizing Dose for Manned Aeronautical Systems" SAA-TN-75-7 Air Force Weapons Laboratory, Kirland AFB, N.M., August 1975.

Table I Radiation Susceptibility of Various Semiconductors

Radiation Environment	Discrete Bipolar Transistors and JFET	Silicon Controlled Rectifiers	TTL	Analog Power Schottky TTL	Analog Integrated Circuits	CMOS	NMOS	Light-Emitting Diodes	Isoplanar II ECL
Neutrons (n/cm^2)	$10^{10}-10^{12}$	$10^{10}-10^{12}$	10^{14}	10^{14}	10^{13}	10^{15}	10^{15}	10^{13}	$>10^{15}$
Total dose (rads (Si))	$>10^4$	10^4	10^6	10^6	$5 \times 10^4-10^5$	10^3-10^4	10^3	$>10^5$	10^7
Transient dose rate (rads (Si)/s) (upset or saturation)	-	10^3	10^7	5×10^7	10^6	10^7	10^6	-	$>10^8$
Transient dose rate (rads (Si)/s) (survival)	10^{10}	10^{10}	$>10^{10}$	$>10^{10}$	$>10^{10}$	Latches $\geq 5 \times 10^7$	10^{10}	$>10^{10}$	10^{11}
Dormant total dose (zero bias)	$>10^4$	10^4	10^6	10^6	10^5	10^6	10^4	$>10^5$	$>10^7$

Base Escape	0-100 rads (silicon)
Radioactive Cloud Penetration	
Cloud Immersion	0-160 rads (silicon)
Plenum Chamber Dust Accumulation	0-1300 rads (silicon)
Miscellaneous	0-200 rads (silicon)
Hostile Territory Penetration	
Prompt Radiation	0-160 rads (silicon)
Neutron Interaction with Vehicle	0-200 rads (silicon)
Fission Product	0-50 rads (silicon)
Damage Assessment	0-100 rads (silicon)
Total Mission Equipment Ionizing Dose	0-2270 rads (silicon)

TABLE II. DOSE ACCUMULATION DURING A REPRESENTATIVE MISSION

The same report considered a neutron fluence of 10^{12} n/cm^2 (1 MeV SDE) which only contributed about 150 rads (Si) to the total dose for the equipment, but results in about a 4000 rads (tissue) dose for the crew (assuming no shielding). However, a single exposure to 10^{12} n/cm^2 (1 MeV SED) corresponds to a gamma dose rate of about 4 X 10^8 rads (Si)/sec. This level is beyond the threshold of latchup for CMOS and is approaching the point where even other kinds of integrated circuits, e.g. T^2L, could latch up. Therefore designers may be driven to exotic, non-standard design techniques to meet the requirement.

However, since the neutron fluence is a permanent effect, the impact would be the same (almost) whether there was one exposure of 10^{12} n/cm^2 or three exposures of 3^+ X 10^{11} n/cm^2 each. On the other hand, the gamma dose rate results in a transient effect and is non-cumulative. If the equipment can survive one exposure to a gamma rate environment, it should survive any number (the cumulative dose increase per gamma pulse is just a few rads (Si)). A neutron fluence of 10^{12} n/cm^2 (1 MeV SDE) is quite compatible with the thresholds of table I and the associated crew dose of 4000 rads (tissue) plus the roughly 1000 rads (tissue) associated with 970 rads (Si) filter air equipment dose matches the 5000 rads (tissue) crew dose.

The nuclear criteria below:

neutron fluence	10^{12} n/cm^2 (SDE)
gamma dose rate	10^8 rads (Si)/sec (and associated delayed gamma dose rates)
gamma total dose	1000 rads (Si) (filtered air)
	2300 rads (Si) (unfiltered air)

are based on a firm foundation, they are highly defendable from a mission/scenario standpoint, they are balanced, and they are just above threshold levels of susceptibility - hence achievable with minimal effect.*

Although the criteria above fit the manned penetrator perfectly, they also afford a degree of surprise resistance for even non-penetrators, e.g. tankers, stand-off missile launches, command and control aircraft, and command post aircraft. In the future, the enemy may develop methods of detecting these aircraft, and if he can locate them, he can attack via ICBMs, SLBMs, penetrating aircraft with air to air missiles or other means. Hardness to the above criteria minimize the potential "achilles heels" at little extra cost.

Of course, the major benefit from the Air Force wide adoption of these criteria is commonality and the tremendous advantages gained from such commonality.

Hopefully, the argument for commonality is so strong and defendable that even skeptics are moved. However, they would possibly concur in the need for commonality but would vigorously attack the need for prompt nuclear radiation criteria. Their idea of commonality may be the absence of prompt nuclear radiation criteria on the grounds that:

1. The enemy would not defend his home territory using nuclear warheads because of the associated collateral damage.

2. He could not detect low-flying, fast penetrators.

3. If he did use nuclear warheads, the required keep out ranges would be so large as to be unattainable.

4. Hardening from the inherent hardness levels to the criteria commended above is not cost effective. Since the keep out range is proportional to the square root of the prompt environment, a hundred fold increase in hardness results in only about a ten-fold incease in keep out range.

Although there may be other arguments against prompt nuclear radiation criteria, the ones above are probably the most notable.

* It can be argued that such levels are ideal — they are high enough to force the design to consider them, but low enough to be readily achieved.

I can't dwelve deeply into the first. I am not able to read the minds of potential enemies. I will note that newspaper articles report that mention of our possible development of small, enhanced radiation devices (neutron bombs) appear to bring forth howls of protest from communist countries (doth they protest too much?) It would be very presumptuous on our part to assume that we alone have the technology to manufacture such small, low-yield, clean nuclear warheads (which would be very effective for air defense as well as for the attack of tanks). Although the blast environment from such a device may be less than standard nuclear warhead, it still would be much more forceful than that of a conventional warhead. Collateral effects would also be relatively insignificant.

Enemy capability is also the major consideration of the second point above. If he doesn't already have it, he could possibly develop the technology to detect, track and attack our low-level penetrators. Therefore it behooves us to incorporate into our systems flexibility to counter improved enemy defenses.

The third argument tacitly assumes large-yield nuclear weapons, which do have large kill ranges but result in the large collateral effects well. As discussed above, a more logical defense would rely on low-yield, clean devices. The keep out ranges then are more reasonable and can be attained with realistic nuclear radiation criteria.

Responses to the fourth argument include (1) while the keep out range is indeed proportional to the square root of the prompt environment, the lethal volume is another story. The aircraft-centered lethal volume is the volume in which a detonation could occur and cause mission kill, and is proportional to the keep out distance to the third power. Therefore an increase in the neutron fluence form 10^{11} n/cm^2 to 10^{12} n/cm^2 results in a 37.5% decrease in the keep out range (from 3200 ft to 2000 ft) but a 76% decrease in the lethal volume (from .932 miles^3 to .228 miles^3). Because of the uncerteinity inherent in even the best of defensive systems, the concept of a three-dimensional lethal volume may be more pertinent than a one-dimensional keep out range. (2) Another rebuttal is that the incorporation of specific design-to nuclear radiation criteria make the definition of keep out ranges, or lethal volumes easier and more accurate. Since the hardness levels of unhardened system vary across subsystem, across system, and with time, the definition of precise keep out ranges or lethal volumes is impossible. The lack of such precision could seriously impact the future development of advanced ECM and/or lethal defenses (high energy lasers, particle beam weapons, or bomber defense missiles) which may be critical to future survivability of the manned penetrator.

The concept of optimal should be expanded here. Optimal implies the most benefit for the least cost. In other words, assume that hardness versus

cost behaved like the curve in figure 2. If cost were the only

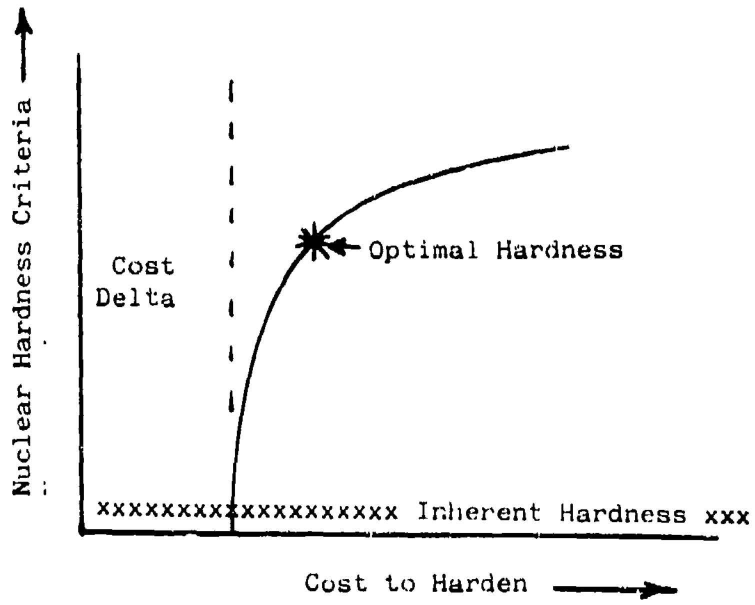

Figure 2. Representative Hardness versus Cost.

consideration then the knee of the curve would be the optimal hardness. (In fact, most system hardness cost relations as a whole do at least roughly correspond to the figure.) Viewing the curve from a procurement standpoint, if there are to be any criteria at all, then the optimal criteria is the logical choice. There is a cost delta associated simply with having the requirement (even if technically it is a non-requirement, i.e., the specified criteria are less than the inherent hardness). Conversely the reduction of criteria from the optimal to some lower level to save money is wishful thinking. Significant savings can be realized only by total elimination of the requirement.

Recently, such a "cost savings" was implemented in an on-going major acquisition program. The results are (1) minimal savings, and (2) the development of a considerable amount of new hardware which cannot be used in new systems with higher criteria unless completely redesigned. We simply cannot afford such "cost saving" measures.

CONCLUSIONS AND RECOMMENDATIONS

It is strongly recommended that the following nuclear radiation hardness levels be immediately adopted as common Air Force requirements and be incorporated into the acquisition of all new and replacement mission critical electronic equipment.

neutron fluence .... 10^{12} n/cm^2 (1 MeV SDE)

gamma dose rate .... 10^8 rads (Si) sec*

gamma dose .... 1000 rads (si) (filtered cooling air)

2300 rads (Si) (unfiltered cooling air)

* Along with the prompt dose rate, a receiver within the atmosphere would be subjected to delayed gammas resulting from interaction of the prompt ionizing radiation with the atmosphere. Such related dose rate(s) should also be included in the criteria.

The above criteria can be vigorously defended, they are achievable with little delta cost, they minimize the possibility of "sports" and "mavericks" in the pieceparts used, they are compatible with cost effective hardness assurance/hardness maintenance procedures, they define keep out ranges which can be used in the development of advanced ECM and lethal defenses, and they provide a basis for common electronic subsystems/components across the Air Force.

The delta cost incurred as a result of incorporating the above criteria is relatively small. If no future threat ever evolved to fully justify the above levels, then we have paid a small price for increased confidence. However, if lower levels were selected and if future threats dictate higher hardness criteria, redesign costs and time required for retrofit would be astronomical... possibly so great that reduced survivality may be the only alternative.

"Dare we not harden?" then is a critical question in the acquisition of new systems.

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